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PROJECT REPORT 9801

ESTIMATING JP-8 AVIATION FUEL EXTRA MAINTENANCE COST

by

Dr. Bao Nguyen

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ABSTRACT

This study assesses the extra maintenance costs when the Canadian Forces use JP-8 aviation fuel. Data were gathered from 4 Wing Cold Lake, and 19 Wing Comox. From the portion of available data, it is concluded that an extra maintenance cost of $278K would be required annually if 19 Wing Comox used JP-8 as their aviation fuel. Approximately $279K is required annually for 4 Wing Cold Lake. These maintenance costs include the cost of extra manpower, and of the parts (such as fuel nozzles) that need to be replaced. It also takes into account potential savings due to lower evaporation of JP-8. As well, a formula to calibrate the fuel gauge based on fuel characteristics is provided.

RÉSUMÉ

Cette étude évalue le coût de maintenance lorsque le carburant JP-8 est utilisé par les Forces canadiennes. Les données recueillies proviennent de la base de Cold Lake, et de la base de Comox. À partir des données disponibles, on peut conclure que si la base de Comox utilise le carburant JP-8, il lui faudra un montant de $278K/année supplémentaire pour la maintenance. Un montant approximativement $279K serait requis pour la base de Cold Lake. Le coût de maintenance inclut le surplus de main d'oeuvre et les pièces qui auront besoin d'être remplacées. Il tient aussi compte les économies dues à la plus faible évaporation du JP-8. Une équation pour calibrer le jauge du carburant est aussi dérivée dans l'annexe du rapport.

EXECUTIVE SUMMARY

In June 1974, NATO nations agreed that the preferred military fuel should be JP-8. As a result of this agreement, all NATO allies, except Turkey, are now using JP-8. In May 1987, Canada committed itself to the use of JP-8 as its standard fuel type in Europe. However, JP-4 is still used at Canadian Forces (CF) Wings within Canada with the only exception of a trial with JP-8 in 1995 at 19 Wing Comox.

In response to the above NATO fuel standardization, 1 Canadian Air Division (1 CAD) is considering the conversion from JP-4 to JP-8. Previous studies indicated that a total annual mean gain of approximately $2.07M could be expected from this conversion. Previous studies also showed substantial gains in operational performance using JP-8 instead of JP-4. For example, due to JP-8's higher density, it could extend the operating range of the CF-18A and in some cases it allows the mission requirements to be fulfilled. It was also shown that, due to its lower volatility, JP-8 is safer than JP-4 e.g. JP-8 reduces the possibility of in-flight and post-crash fires.

However, JP-8 is known in general to increase coking of the fuel nozzles and combustion chambers thereby increasing the requirements for aircraft maintenance. Different CF aircraft have also experienced additional problems. For example, the CT-133 was experiencing recurring over-temperatures on start-up and while flying; the CH-113 heater was not designed to use JP-8 and so experienced lighting difficulties; the low temperature operating envelope of JP-8 imposes significant operational limitation on the CH-146 fleet below –30 ^{0}C etc. All these problems required extra maintenance to operate CF aircraft with JP-8 but the $2.07M result did not include these extra maintenances.

Therefore, the Centre for Operational Research and Analysis (CORA) was tasked by DCOS Maint to quantify the extra maintenance cost associated with JP-8 aviation turbine fuel for CF land-based aircraft. We analyze the cost of extra manpower, and of the parts that need to be replaced. We also take into account potential savings due to lower evaporation of JP-8.

For this study, the above factors were analyzed for two bases and for six different types of aircraft. The bases under study were 19 Wing Comox and 4 Wing Cold Lake. The different

aircraft types include the CF-188 (Hornet), the CP-140 (Aurora), the CT-133 (Silver Star), the CC-115 (Buffalo), the CH-113 (Labrador) and the CC-138 (Twin-Otter).

@RISK, a statistical simulation program was used to compute the total extra maintenance cost at each wing. It was found that if 19 Wing Comox employs JP-8, an annual expected extra maintenance cost will be $278K. This cost includes not only the extra manpower but also the extra cost of more frequent maintenance of the fuel nozzle on the CP-140. For 4 Wing Cold Lake, the annual extra maintenance cost is most likely $279K per year. Since 4 Wing Cold Lake has not used JP-8, this estimated cost is obtained from extrapolating known data gathered during short missions outside of Canada or data from 19 Wing Comox.

In general, SAMEOs at various Squadrons prefer JP-4 to JP-8 due to the burden of extra maintenance when using JP-8. The analysis shows that substantial extra maintenance cost is required when using JP-8. However, we assume that over time, pricing for JP-4 will increase due to limited usage. Therefore, eventual cost increases for JP-4 relative to JP-8 may dictate a switch in the future.

Now that the pro's and con's of using JP-8 for the analyzed aircraft types have been analyzed, it is up to the decision makers to decide whether the CF will convert from JP-4 to JP-8 as its standard fuel. However, we recommend that long term effects on these aircraft be studied before a decision is made.

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ESTIMATING JP-8 AVIATION FUEL EXTRA MAINTENANCE COST

1 - INTRODUCTION

1. JP-4 aviation turbine fuel has been used since the late 1960's for military air operations. It was found that there had been combat losses directly related to fuel fires or explosions. For this reason, the United States Air Force (USAF) initiated an evaluation of a more combat safe fuel. In 1968 [1], JP-8 was selected for further testing. (JP-8 is essentially commercial Jet A-1 with fuel system icing inhibitor (FSII) and corrosion inhibitors added.)

2. In June 1974, NATO nations agreed that the preferred military fuel should be JP-8. As a result of this agreement, all NATO allies, except Turkey, are now using JP-8. In May 1987, Canada committed itself to the use of JP-8 as its standard fuel type in Europe. However, JP-4 is still used in the Canadian Forces (CF) within Canada with the only exception of a trial with JP-8 in 1995 at 19 Wing Comox.

3. In response to the above NATO fuel standardization, 1 Canadian Air Division (CAD) is considering the conversion of JP-4 to JP-8. References [2-3] indicated that a total annual mean gain of approximately $2.07M could be expected from this conversion. It also showed substantial gains in operational performance using JP-8 instead of JP-4. For example, due to the higher density of JP-8, it extends the operating range of the CF-18A, and in some cases, allows the mission requirements to be fulfilled which would not have been possible if JP-4 had been used. Low volatile fuels such as JP-8 are also safer than high volatile fuels such as JP-4 at temperatures experienced in aircraft and ground operations. As JP-8 essentially has no vapour pressure at ambient conditions it is safer to handle than JP-4. However, JP-8 is known to increase coking of the fuel nozzles and combustion chambers thereby increasing the requirements for extra maintenance.

4. The cost of extra maintenance was not included in the $2.07M result. Therefore, the Centre for Operational Research and Analysis (CORA) was tasked by DCOS Maint [4] to quantify the extra maintenance costs associated with the conversion from JP-4 to JP-8 aviation

fuel for land based aircraft. The present paper analyzes the extra maintenance costs based on the available data gathered from 4 Wing (Cold Lake) and 19 Wing (Comox).

5. The properties and descriptions of JP-4 and JP-8 are presented in Section 2. The current key issues relating to the usage of JP-8 are discussed in Section 3. Section 4 presents possible savings that could be realized when using JP-8. Section 5 analyzes the extra maintenance costs at 19 Wing (Comox). Section 6 analyzes the extra maintenance cost at 4 Wing (Cold Lake). We conclude and summarize in section 7.

2 - FUEL DESCRIPTIONS AND PROPERTIES

6. Table 1 displays important fuel properties of JP-4 and JP-8. The main differences between JP-4 and JP-8 are volatility, density and the volumetric heat of combustion. JP-4 fuel also known as F-40 (NATO code) is essentially a 50:50 mixture of heavy naphtha and kerosene. JP-8 fuel also known as F-34 (NATO code) is basically commercial Jet A-1, a kerosene based aviation turbine fuel, plus three military additives: fuel system icing inhibitor, corrosion inhibitor/lubricity improver additive, and static dissipater additive [5].

Property	JP-4	JP-8
Density, kg/m^3	750-801	774-839
Density (Normal Average) (lb/gal)	6.34	6.71
Freezing Point, ^{o}C	-58	-47
Flash Point, min, ^{o}C	-29	+38
BTU's Per gal, min	115,000	119,000
Vapour Pressure, KPA (range)	14-21	0
Initial Boiling Point, ^{o}C (range)	142	329

Table 1 – Important physical properties of JP-8 and JP-4

7. Reference [3] indicates that presently, the only pure JP-8 fuel being produced in Canada is available in Goose Bay, Labrador. However, the cost advantage associated with JP-4 has been disappearing gradually due to decreasing JP-4 refinery production in Canada. We expect that this cost advantage will soon belong to JP-8, as there will be less competition for supplying JP-4.

8. In general, all major refiners have the technology to produce JP-8 fuel. Though, there might be some potential problems of purchasing JP-8. Firstly, refiners would be reluctant at supplying JP-8 fuel to locations where quantities would be considered minimal. Secondly, the unpredictable nature of DND's call-ups to standing offers, with respect to quantities and annual usage patterns, compared to airline business may result in oil companies being unwilling or unable to satisfy DND's needs. Lastly, while commercial aviation companies provide firm quantities to quote on, DND's requirements have no such firm commitments partly due to its unpredictable rate of consumption.

3 - CURRENT KEY ISSUES WITH JP-8

9. References [6-11] provide a series of problems that the Canadian Air Force has experienced when using JP-8 as aviation fuel:

a. Fuel leaks: There were frequent fuel leaks on some aircraft. For example, there were 27 leaks at 414 Squadron on the CT-133 for a three-month period during the JP-8 trial compared to 12 during a three month preceding the JP-8 trial.

b. Hot Start/Over Temperature: Starting temperature was higher than the normal on some aircraft. For example, the CT-133 was experiencing recurring over-temperatures on start-up and while flying. This could lead to excessive engine and turbine stress.

c. Coking: When burning JP-8, increased coking and power loss is expected. Since JP-8 is a heavier fuel, it produces more carbon and thus more soot, which cokes the engine and creates a subsequent engine power loss, as the engine becomes dirtier. Small turbine engines (Accelatory Power Units, APUs) are mostly affected by coking, and fuel leakage. And they are difficult to start below -26^{0}C. Note that the fuel nozzle is replaced every 1,200 hours in other countries when using JP-8. The Canadian Forces replace them every 6,000 hours.

d. CH-113 Labrador Heater: The CH-113 cabin heater was not designed to use JP-8 as the on-board fuel. This heater experienced lighting difficulties and fuel pooling due to JP-8. Some CH-113 aircraft even caught fire.

e. CH-146 Griffon: The low temperature-operating envelope of JP-8 would impose a significant operational limitation on the Griffon fleet below -30^{0}C.

f. Refueling trucks: The filters on the refueling trucks in 19 Wing Comox had to be replaced as the JP-8, during the trial, was thicker and dirtier than JP-4.

g. JP-8 quality: The quality of JP-8 can vary widely within specification depending on the source of the petroleum and the refinery process. For instance, the Royal Australian Air Force (RAAF) has been using their specific JP-8 for a long time and has had the fewest problems. This RAAF solution might be a solution for the CF.

4 - POTENTIAL SAVINGS WITH JP-8

10. The following are potential sources of savings when using JP-8 as aviation fuel:

a. Bulk Storage Tanks: Prior to any bulk storage tank maintenance, all JP-4 fuel must be removed and the fuel vapour purged. It takes 2.5 to 3 hours to purge the JP-4 fuel vapour from most of the tanks before the LEL (Lower Explosive Limit) standards are met. On average, it takes 1-3 hours to clean the tank. However, larger tanks can take up to 16 hours. Due to the low vapour pressure of JP-8, there would be no need for purging of fuel vapour before bulk tank storage maintenance can proceed [2].

b. Losses Due to Evaporation (Working Losses): During transport from the refinery to the bases, the fuel undergoes at least one fill/drain cycle. For each fill/drain cycle the amount of JP-4 lost due to evaporation is estimated to be 0.06 percent of the amount being transferred. These losses are called "Working Losses". With its higher density and lower volatility, this evaporation loss does not occur with JP-8 fuel.

c. Losses Due to Evaporation (Standing Losses): Losses due to evaporation from the bulk tank storage are called "Standing Losses". Reference [5] estimates a standing loss of 1.67 percent per year for JP-4 based on a Reid vapour pressure of between 2

and 3 psi. Standing losses for JP-8 are negligible due to its higher density and lower volatility.

d. Vapour Control System: If Canada faced the same level of environmental standards as the United States, the CF would be required to equip their bulk storage fuel tanks with vapour control systems. If JP-8 became the main CF fuel, these vapour control systems would not be required due to JP-8's much lower evaporation rate.

e. Reduced Manpower for Fuel Servicing: During any aircraft refueling operation, there are normally three persons: 1 500-Series Tech, 1 person operating the fuel flow from the truck and 1 person standing by with a fire extinguisher in case of an accident or fire. The larger aircraft, which have more than one vent and multiple fuel nozzle connections, often require more than three people. As the volatility of JP-8 is much less than of JP-4, refueling personnel could be reduced and safety standards could be relaxed with JP-8 [5].

f. Aircraft Maintenance Costs: To ensure that the aircraft is safe to work in and around, there are specific steps that must be taken prior to any aircraft maintenance procedure. For the procedures involving any part of the aircraft fuel system or fuel tanks, the aircraft tanks must be drained of all fuel and then purged with air, to remove fuel vapour, until the Lower Explosive Limit (LEL) is reached. It might take anywhere from 18-24 hours of purging until the LEL reaches the 10% standard requirement. According to a USAF study [5], the purging operations of aircraft tanks prior to maintenance was unnecessary with the use of JP-8. However, this does not apply to the CF even when using JP-8. The ventilation and purging of aircraft fuel systems must still be done before any work can be performed on the fuel systems or fuel tanks [2]. Therefore, there are no cost savings realized in the aircraft maintenance cost.

5 - 19 WING COMOX

11. 19 Wing Comox currently operates four CH-113 Labrador (442 Squadron), six CC-115 Buffalo (442 Squadron), five CP-140 Aurora (407 Squadron) and thirteen CT-133 Silver Star (414 Squadron) aircraft. References [9,12] indicate that the Buffalo and the Aurora have no obvious problem with JP-8 in the sense that there is no extra maintenance effort required when using JP-8. There were somewhat more problems for the Aurora but none of them could be clearly linked to JP-8. Reference [13] indicates that there might be turbine damage for the Aurora with long term use. In general, the long-term effect on aircraft due to JP-8 is unknown at 19 Wing Comox, as it did not employ JP-8 for a very long period.

12. @RISK, a statistical simulation program was used to compute the total extra maintenance cost per year. Stable output from 4000 iterations of a Monte Carlo simulation allowed determination of the statistics of the total extra maintenance cost. In the absence of completely exact data, we assume that the total hourly cost of a technician (Sergeant [14]) for maintenance of an aircraft obeys a triangular distribution with an average (minimum, maximum) of $30 ($20, $40). We also assume that the price of JP-4 at 19 Wing Comox is normally distributed with mean $0.2810/L and standard deviation $0.0074/L, [2].

13. CH-113 Labrador: With JP-8 fuel, the Labrador requires extra cleaning of the igniter, exhaust, and compressor. Cleaning igniters requires a maximum 2 extra man-hours per aircraft per day [9]. We assume a minimum of 1 extra man-hour, a most likely of 1.5 extra man-hour, and a maximum of 2 man-hours per aircraft per day. Cleaning the exhaust takes an extra 2 to 4 man-hours per week. Cleaning the compressor requires an extra 14 to 18 man hours per aircraft every six months. In a one-year period, this extra maintenance cost is equal to an expected value of **$74.2K**. At the time of the JP-8 trial, 442 Squadron had a surplus of manpower and so this was not a problem. However, this surplus of manpower might not be available in the future if 19 Wing Comox decided to use JP-8 as their aviation fuel.

14. Reference [7] indicates that the fuel seals were replaced on the CH-113 due to fuel leaks when using JP-8. However, these seal replacements are part of the routine maintenance on the CH-113 [8]. Therefore, we do not include expenses of these fuel seals. To operate the CH-113 properly, the accelatory power unit and the cabin heater on the CH-113 need to be replaced [9].

These are known to be expensive and so far there has been no serious study to replace them. Therefore, these potential costs are not included in our calculation.

15. CT-133 Silver Star: The CT-133 engine had experienced coking and fuel leaks. The coking phenomenon resulted in a power loss and difficulties in starting the engine. Occasionally, the burner on the CT-133 had to be replaced. In a three month period, when using JP-8, there were 27 fuel leak snags compared to 12 during the three month period preceding the trial of JP-8. This is strong evidence that JP-8 is related to fuel leaks on the CT-133. The CT-133 was also experiencing over-temperature on start-up and while flying. This could lead to excessive engine and turbine stress [7]. Extra maintenance and part replacements on the CT-133 were required to operate the CT-133 during the trial of JP-8.

16. The extra maintenance is evaluated to be on average (minimum, maximum) one extra man-hour (0.5, 1.5) per aircraft per day [10]. The CT-133 operates five days a week. Therefore, in a one-year period, this extra effort is expected to be equal to $101.4K.

17. The extra part replacements cost $2.9K from 23 August 1995 to 22 November 1995 [10]. There are two main sources of uncertainty to this cost. Firstly, this cost will decrease with time, as some of the part replacements are a one-time initial cost. Secondly, pricing of these items might increase as much as 200% since these costs do not reflect current market prices. We assume that it might increase anywhere from 0% to 200%. If we extrapolate the data from the two month period, we get a part replacement annual cost ranging from $17.4K to $54.6K when using JP-8. The total extra maintenance cost to operate the CT-133 fleet when using JP-8 is therefore most likely to be **$136.2K** per year.

18. Although, it is expected that the extra maintenance to operate the CT-133 decreases with time, we also expect that engine damage increases. The latter factor can not be quantified because it is a long-term effect and 19 Wing Comox did not employ JP-8 for a long period. It is felt that to run the CT-133 on JP-8, in the long run, each CT-133 might require a fuel control unit and a burner replacement every 100 hours. So far, there has been no study to assess these costs. To avoid misleading estimates, we only acknowledge these potential costs but do not include them in this report.

19. CP-140 Aurora [13,15]: In general, the Aurora had no problems running on JP-8. There might have been more fuel leaks when using JP-8; however, these fuel leaks were within the same standard bound as with JP-4. There were frequent fuel reading discrepancies when the Aurora was refueled with JP-8, (i.e., the gauge reading in the aircraft differs from the one on the bowser by more than 1,000 lbs). When this happens, the technicians have to measure the volume of fuel in each of the five tanks of the Aurora by dipping in a meter stick in each tank. They then calibrate the defective gauges on the aircraft. This operation takes on average 2 man-hours per fuel gauge job with three to six fuel jobs per day. Assuming that one to three gauges require calibration per fuel job, the annual extra cost for calibration of the Aurora's fuel gauge is on average $197.1K. However, [16] indicates that the reason there were so many problems with the fuel gauge reading is unknown and is not clearly associated with JP-8. On a macroscopic scale, this extra cost of $197.1K does not occur i.e., it did not require an extra technician. If 407 Squadron used JP-8 permanently then replacing the fuel gauge on the CP-140 could be an option although a firm cost for such a replacement is not available. It is the opinion of the author that the fuel gauge calibration cost is a one-time only cost if the aircraft employs only one type of fuel i.e., the routine calibration of the fuel gauge should be the same for JP-4 and for JP-8, otherwise, there might be unknown problems with the fuel gauge. The labour cost of calibrating all the fuel gauges for all five CP-140 is on average $1.2K. Annex A provides a formula to calibrate the fuel gauge as a function of fuel characteristics.

20. The engine bay personnel indicated that they had no more problems with JP-8 than with JP-4. There were also no differences in engine performance between JP-8 and JP-4. In the long run, if the Aurora runs on JP-8, it is felt that the igniters might require more frequent replacement.

21. Reference [13] suggests that when using JP-8, the Aurora's fuel nozzles need to be cleaned and replaced every 1200 flying hours instead of every 6000 flying hours. Based on historical flying hours, this is equivalent to an average (minimum, maximum) 2.6 (2.3, 2.8) fuel nozzle cleanings per year per aircraft. For five CP-140, this gives a total of 13 (11.5, 14) fuel nozzle cleanings per year. For each fuel nozzle check, it requires 12 man-hours at base level for removal and installation, and would cost $950 for cleaning and flowing at third line, [13]. The cost of cleaning the fuel nozzle would be expected to be $16.5K.

22. In addition to this maintenance cost, an average (minimum, maximum) of 20% (15%, 25%) of the fuel nozzles need to be replaced at each cleaning. This amounts to an average (minimum, maximum) of 2.8 fuel nozzle replacements per year. For each of the four engines per aircraft, there are 6 nozzles, each costs $1,200. Therefore, the cost of replacement would be on average (minimum, maximum) $80.6K ($60.8K, $100.4K). The total extra cost of cleaning and replacing the fuel nozzles at 19 Wing Comox according to [13] would be expected to be **S77.7K**. Combining the extra cost associated with the fuel nozzle and the extra cost of calibration gives us a total extra maintenance cost of $275.0K per year for the Aurora fleet.

23. Bulk Storage Tanks: 19 Wing Comox has five tanks of 909,218 Litres each [2,12]. Reference [2] estimates a potential saving of 60 man-hours every three to five years. As 19 Wing Comox only utilized JP-8 for less than one year, this saving was not clear and so will not be included in this analysis.

24. Refueling Trucks: The turbo filters for the 11 refueling trucks were replaced due to the heavier density and quality of JP-8 [17]. Each filter costs $1,380 (NATO Stock Number 4330-21-896-6007). For eleven of these filters, this amounts to **$15,180**. We assume that this is an annual cost as the JP-8 trial lasted for approximately one year.

25. Working Losses: The maximum quantity of fuel that can be supplied to 19 Wing Comox is 30 Million Litres per year. With a working loss rate of 0.06%, a maximum of 18 K Litres per year would be lost due to evaporation during delivery. However, the maximum quantity is not always ordered every year. Therefore, for statistical purposes, we assume that fuel volume supplied to 19 Wing Comox follows a triangle distribution where the minimum volume is 60 percent of the maximum volume (18 Million Litres) and the most likely volume is 80 percent of the maximum volume (24 Million Litres). Therefore, the annual average savings due to working loss are equal to **$4.0K**.

26. Standing Losses: The total tank capacity at 19 Wing Comox is 4,546,090 Litres. With a standing loss rate of 1.67 percent, the fuel loss at 19 Wing Comox due to evaporation from the bulk storage tanks is 75,919 Litres per year. This amounts to average annual savings of **$21.3K**.

27. Vapour Control Systems: If 19 Wing Comox maintained the same environmental regulations as the USAF, it would need a vapour control system for its bulk storage tanks. An estimated **187,500 (US$)** would be expected for the five medium sized tanks at 19 Wing Comox [2]. This would not be required if the fuel were JP-8.

28. Reduced Manpower for Fuel Servicing: Safety standards were not relaxed during the JP-8 trial and so the same number of people were needed during aircraft refueling [18]. The analysis assumes safety standards would not be reduced and therefore there will be no expected savings in this area.

29. Aircraft Maintenance Costs: The same procedures for the ventilation and purging of aircraft fuel systems were performed on the fuel system and fuel tanks during JP-8 trial, [18]. Thus, there were no savings in this aspect of aircraft maintenance procedures involving the fuel systems or fuel tanks of aircraft.

30. Total Extra Maintenance Cost: The total extra annual maintenance cost at 19 Wing Comox when using JP-8 is the sum of all extra maintenance costs subtracted by the sum of savings. From the rough data that we received, we assume triangular distributions to produce statistical results. We also assume an exchange rate of $1.47 for 1US$. The estimated extra annual maintenance cost at 19 Wing Comox when using JP-8 is expected to be $278.0K a year or $475.0K a year if we associated the calibration cost of fuel gauges to JP-8.

31. If 19 Wing Comox were subject to the same environmental standard as the US, it would need $275.6K to equip vapour control system when using JP-4. Assuming this cost is spread over five years, 19 Wing Comox saves an extra $55.2K per year by switching to JP-8 because vapour control systems are not needed when using JP-8 due to its lower volatility. In total, if 19 Wing Comox faced the US environmental standard, the expected extra maintenance cost would be **$223.9K** a year for the first five years. Note that we do not include the difference in price of JP-8 and JP-4, as this is not part of the maintenance cost.

32. Figure 1 displays the distribution of the total annual extra maintenance cost associated with JP-8 in 19 Wing Comox. It assumes that the CF would not face the same environmental regulations as the ones faced by the USAF. Figure 1 is generated from 10,000 Monte Carlo iterations. The most likely extra maintenance cost is about **$270K**. To 99%, the extra maintenance cost is bounded from $170K to $380K.

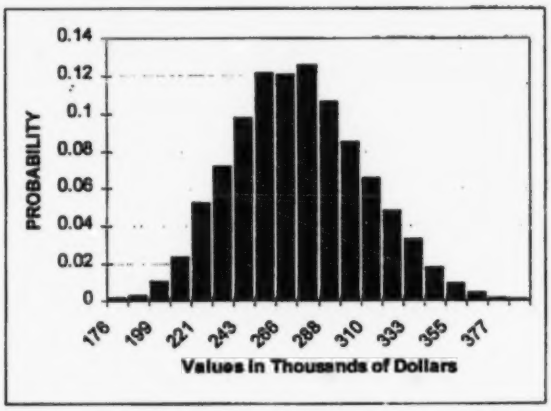

Figure 1 – Distribution of annual extra maintenance cost at 19 Wing Comox due to JP-8

6 - 4 WING COLD LAKE

33. 4 Wing Cold Lake manages 410, 416, 440, 441, 417 Squadrons, 10 FTTS, and AETE. The extra maintenance cost will be analyzed from each of these Squadrons. Some of these costs are simply extrapolations from known data of 19 Wing Comox. We assume that two aircraft of the same type require the same extra maintenance cost. The total extra maintenance cost at 4 Wing is the sum of the costs at each Squadron and the transport costs.

34. 416 Squadron [19,20]: 416 Squadron has twenty-two CF-18s. While at 4 Wing Cold Lake, these aircraft employ JP-4. However, when these aircraft are abroad, JP-8 is often used. When using JP-8, these aircraft experience some of the problems mentioned in Section 2. For example, there are fuel leaks on these aircraft when using JP-8. From 15 August to 1 November 1997, 117.3 man-hours were spent on extra maintenance to six CF-18s due to JP-8 usage. This implies an average (minimum, maximum) annual extra maintenance cost of **$61.9K** ($41.4K, $82.2K).

35. 441 Squadron [21]: 441 Squadron operates 15 CF-18s. When on US and 19 Wing Comox deployments, these aircraft sometimes use JP-8. On the first few days of conversion to JP-8, there are normally fuel leaks. After replacement of the fuel seals, this problem goes away. During the time of JP-8 usage, there has been no engine coking. However, these aircraft have never run on JP-8 for a period longer than three weeks. Therefore, long term effects on the engine are unknown. Over the last three years there have been 12 deployments of these aircraft, with three to ten CF-18s participating in each deployment. Prior to each deployment, 90% of the fuel/heat exchanger O-rings ($0.53 a piece) were replaced. There are four O-rings on each CF-18. It takes 10 to 20 minutes for two technicians to replace a set of four O-rings. The extra maintenance cost associated with the O-rings, per year at 441 Squadron, based on the above information is expected to be $0.5K. Extrapolating data of 416 Squadron, we obtain an additional and potential maintenance cost of $42.2K per year. Therefore, the total extra maintenance cost per year at 441 Squadron is most likely **$42.7K.**

36. 410 Squadron [22]: 410 operates 23 CF-18s. 410 Squadron usually does not fly with JP-8 fuel. On their two most recent experiences with JP-8 in the US, 410 Squadron personnel did not identify any coking or leakage problems. The maintenance personnel did replace the O-rings during one of these two deployments. Extrapolating the data of 441 Squadron, we estimate that a total extra maintenance cost per year is expected to be **$65.4K.**

37. 440 Squadron [23]: 440 Squadron has four CC-138 (Twin-Otters). These aircraft can run on most types of fuel. Therefore, they have no problems when using JP-8. There is very slight coking when using JP-8, which would not lead to any extra engine maintenance and would only result in a dirtier aircraft. This coking requires approximately one extra hour of maintenance for each wash job. There are on average (minimum, maximum) 16 (15.5, 16.5) wash jobs annually, therefore, implying an average (minimum, maximum) extra maintenance cost of **$0.5K** ($0.3K, $0.6K).

38. 10 FTTS [14]: 10 FTTS operates one CT-133. In absence of hard data, we extrapolated the costs from 19 Wing Comox. This gives an average extra annual maintenance cost of **$10.5K.**

39. 417 Squadron [14]: 417 operates three CT-133 and three CH-146. No data on the CH-146 was available. However, [24] indicates that JP-8 is an acceptable fuel for the CH-146. But Reference [2] shows that the CH-146 experiences problems when starting at low temperature. Again, extrapolating data from 19 Wing Comox, the annual extra maintenance cost for the CT-133 is most likely **$31.5K**.

40. AETE [14]: AETE operates two Tutors, six CT-133, two CH-146 and four CF-18. It is expected that the extra maintenance on the Tutor is minimal. Extrapolating from the previous data, the extra maintenance cost for the CT-133 and the CF-18 is expected to be **$74.1K** per year.

41. Reference [25] indicates that there would be less savings in working loss and standing loss in 4 Wing Cold Lake than in 19 Wing Comox. This is due to the long period of cold weather in Cold Lake, which minimizes evaporation of fuel. Assuming that the low temperature season lasts for six months every year, and based on a maximum consumption of 145 Million Litres and 16.8 Million in tank storage, the savings in working loss and standing loss [3] is expected to be **$38.2K** per year.

42. With 23 refueling trucks in 4 Wing Cold Lake [26], an average cost of **$31.7K** is expected for replacing the turbo filters on each truck when using JP-8. This value is obtained from extrapolating 19 Wing Comox data.

43. Summing up all extra costs associated with JP-8, we obtain an average (minimum, maximum) annual extra maintenance cost, in 4 Wing Cold Lake, of **$278.8K** ($170.8K, $406.0K). We assume that there would be no reduced manpower for fuel servicing and no reduced aircraft maintenance cost if 4 Wing Cold Lake employed JP-8. Unlike 19 Wing Comox, 4 Wing Cold Lake's storage tanks are equipped with vapour control systems [26]. However, these vapour control systems can not recover lost fuel. That is why we included the standing loss in the total extra maintenance cost. Note that this cost does not include extra maintenance cost (if any) for the CH-146 Griffon.

44. In general, JP-4 is preferred to JP-8 in 4 Wing Cold Lake, [25]. Firstly, aircraft run better with JP-4 than with JP-8 at low temperature. Secondly, the fuel refineries are located in Alberta. Therefore, JP-4 is relatively cheap to buy in Cold Lake.

45. Figure 2 displays the extra annual maintenance cost at 4 Wing Cold Lake. It is generated from 10,000 Monte Carlo iterations. The most likely extra maintenance cost is approximately **$280K**. To 99%, the extra maintenance cost is bounded from $170K to $380K.

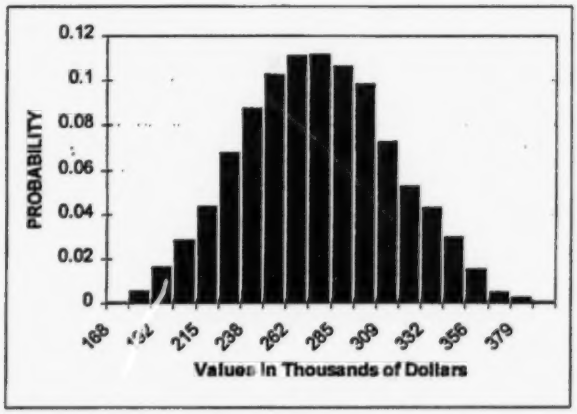

Figure 2 - Distribution of annual extra maintenance cost at 4 Wing Cold Lake due to JP-8

7 - SUMMARY AND CONCLUSIONS

46. The extra annual maintenance costs at 19 Wing Comox and 4 Wing Cold Lake are displayed in Table 2 below. Note that the extra maintenance cost, in brackets, of 407 Squadron is a potential cost, which includes the debatable calibration cost of the fuel gauge on the CP-140. Note also that the extra Wing maintenance cost at 19 Wing Comox includes transport costs such as the cost of fuel seal replacement on refueling trucks, and storage savings due to reduced working loss. The extra transportation costs in 4 Wing Cold Lake is an extrapolation from 19 Wing Comox calculations. Data for 4 Wing was not available since 4 Wing Cold Lake did not trial JP-8. The extra maintenance cost at each Wing would be less if it were subject to the same environmental standard as the one in the USAF, because JP-8 would not require the vapour control systems necessary for JP-4.

47. Some of the values displayed for 4 Wing Cold Lake is simply extrapolations from known data. As Comox had a real trial with JP-8 and the data we gathered are from that trial, the cost obtained for 19 Wing Comox is more reliable than the ones for the CF-18 Squadrons. The cost for 4 Wing Cold Lake are only lower bounds since we did not have data on the extra maintenance cost for the Griffon. In fact, all these costs are lower bounds, as long-term costs are not factored into the calculation. Note that the difference in price between JP-8 and JP-4 is not included in this calculation, as it is not a maintenance cost as such. The potential cost of replacing the cabin heater and APU on the CH-113 is also not included.

Wing	Units	(Expected) extra annual maintenance cost	Total extra maintenance cost for the Wing	
			Without US standard	With US standard
19 Wing Comox	407 Squadron 414 Squadron 442 Squadron	\$78.9K(\$275.0K) \$136.2K \$74.2K	\$279.1K (\$475.0K)	\$223.9K (\$419.8K)
4 Wing Cold Lake	410 Squadron 416 Squadron 440 Squadron 441 Squadron 10 FTTS AETE 417 Squadron	\$65.4K \$61.9K \$0.5K \$42.7K \$10.5K \$74.1K \$31.5K	\$278.8K	

Table 2 – Extra maintenance costs per year at different units when using JP-8 as aviation fuel

48. There is 90 percent chance that the above extra maintenance cost at 19 Wing is less than $340K when US standard is not imposed. On average, at 19 Wing, the extra labour contributes to $188K, the extra part replacement to $114K, and savings to -$25K annually.

49. The 90 percent figure for 4 Wing is approximately the same for 19 Wing. However, the breakdown costs are different. On average, at 4 Wing, the extra labour is $258K, the extra part replacement is $59K, and savings are -$38K annually.

50. In general, JP-4 is preferred to JP-8 both in 19 Wing Comox and 4 Wing Cold Lake, [9,25]. The analysis shows that substantial extra maintenance is required when using JP-8. However, we assume that over time, pricing for JP-4 will increase due to limited usage. Therefore, eventual cost increases for JP-4 relative to JP-8 may dictate a switch in the future.

51. Due to the unavailability of data, we were limited to analyze only the available portion. The complete calculation of the maintenance cost could be complex. We therefore recommend a more comprehensive study, which includes all Wings in the Canadian Forces when complete data is available.

52. As was explained in the text, there are some serious issues when using JP-8. It would be valuable to find out how other NATO countries deal with their problems associated with JP-8. This might point the CF towards solutions associated with JP-8.

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ANNEX A: FUEL GAUGE CALIBRATION FORMULA

A1. The extra cost of calibrating the fuel gauge could be substantial. It is approximately $191K a year for the Aurora fleet of 407 Squadron. Therefore, an analytical formula for calibration could help reduce this extra cost.

A2. The fuel gauge is a cylindrical capacitor with an inner conductor of radius a and an outer coaxial cylindrical conductor of inner radius b and outer radius c ($a < b < c$). The coaxial capacitor is immersed in a reservoir of liquid dielectric (fuel) with mass density ρ. If a potential difference V is applied, the liquid will rise to a height h between the plates. If we neglect edge effects, the following formula [27] is obtained for h:

$$h = \frac{2\chi_e \varepsilon_0 V^2}{\rho g (b^2 - a^2) \ln(b/a)}$$

where g is the gravitational acceleration (9.8 meter/sec^2), ε_0 is the permittivity of free space (8.85×10^{-12} farad/meter), χ_e is the electric susceptibility of the fuel and V is the potential difference of the capacitor (in volts).

A3. The fuel gauge converts the capacitance into pounds. We provide here a formula of how to obtain this conversion. This formula can be used to calibrate the fuel gauge. Let the capacitor be of total length L, the fuel level be L_f and the capacitance C, we get the following relationship:

$$L_f = \left(C - \frac{2\pi\varepsilon_0 L}{\ln(b/a)} \right) \frac{\ln(b/a)}{2\pi\chi_e\varepsilon_0} - h$$

A4. We see that the fuel level is a linear function of the capacitance. For illustration, assume the fuel tank is a cylinder of radius r, then the weight of fuel at fuel level L_f is equal to the following:

$$2\pi r L_f \rho = 2\pi r \rho \left(C - \frac{2\pi\varepsilon_0 L}{\ln(b/a)} \right) \frac{\ln(b/a)}{2\pi\chi_e\varepsilon_0}$$

A5. This is the conversion formula from capacitance to fuel weight where we have neglected h. It can be seen that the fuel weight is a function of the fuel density ρ and the electric susceptibility of the fuelχ_e. Clearly, each time we use a different fuel – therefore a different ρ and a different χ_e, we need to calibrate the gauge using the above formula.

A6. To give us an order magnitude of h, we calculate it based on rough parameters. Assume the mass density is about 800 kg/m^3, χ_e be of order 1, V of order 10 Volts, b of order 0.2 m, a of order 0.04m, g is equal to 9.8 m/sec^2.), ε_0 is equal to 8.85x10^{-12} farad/m, we get h of order 10^{-12} m. Note that this is in no way an exact calculation but it tells us that h is negligible.

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This study assesses the extra maintenance costs when the Canadian Forces use JP-8 aviation fuel. Data were gathered from 4 Wing Cold Lake, and 19 Wing Comox. From the portion of available data, it is concluded that an extra maintenance cost of $278K would be required annually if 19 Wing Comox used JP-8 as their aviation fuel. Approximately $279K is required annually for 4 Wing Cold Lake. These maintenance costs include the cost of extra manpower, and of the parts (such as fuel nozzles) that need to be replaced. It also takes into account potential savings due to lower evaporation of JP-8. As well, a formula to calibrate the fuel gauge based on fuel characteristics is provided.

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Statistics